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ECL 274

THE RUNAWAY SOURCEHEAD

A 2800 pound sourcehead of a radiation teletherapy device fell suddenly and fatally injured a patient. Was this accident caused by defective mechanical design, inadequate maintenance, improper operation, or some combination of the above?

Written by J.D. Gibson, Department of Mechanical Engineering, Rose-Hulman Institute of Technology, Terre Haute, Indiana.

Joe Williams* had been working for Reliable Engineering Consultants, Inc. less than two years after his graduation when one afternoon his boss told him to return a call to a Mr. Thompson, an attorney in St. Louis.

During the ensuing telephone conversation Thompson indicated that his law firm had been retained as defense council by Valley Medical Clinic. A suit had been filed against Valley by the family of a Mrs. Greene who had been fatally injured during radiation treatment for a tumor. The suit filed by the attorney representing the family of Mrs. Greene, Mr. Rhoades, alleged that Valley had been grossly negligent during the treatment of Mrs. Greene and had caused her death and the resulting suffering of her family. Thompson further stated that the allegations of the plaintiffs (Greene/Rhoades) and the counter arguments of the defense (Valley/Thompson) would inevitably involve discussions of mechanical design and therefore he would like to retain the services of Reliable for engineering consultation and possible use in court as expert witness. After conferring with his boss Williams called Thompson back and agreed to help him with the case. Thompson and Williams arranged a meeting one week later at the Valley Medical Clinic, the site of the accident, so that Williams could inspect directly the radiation unit that had been involved in the accident.

At the inspection and meeting with Thompson, Williams was able to examine the failed teletherapy unit and to develop a better understanding of how a heavy (2800 pound) radiation sourcehead could be accurately positioned vertically. He observed that a rotating ball screw was used to produce linear vertical motion of the sourcehead. Williams noted further that the ball screw was driven by an electric motor through a V-belt to a gear reducer (non-reversible worm gear) and then to the ball screw through a two piece coupling with a rubber interface (spider).[2] The vertical load on the screw was transferred to the base of the assembly by means of a thrust bearing. The operator of the radiation unit controlled the vertical position of the sourcehead by means of a hand control which started, stopped, and reversed the electric motor.

Although the components of the teletherapy unit had been inspected previously by others and had been rearranged to some extent, it was obvious to Joe Williams that the sourcehead which contained the radioactive source and its shielding had dropped suddenly to the floor. The screw had spun in the ball nut so rapidly that when the sourcehead hit the floor the angular momentum of the screw had evidently caused it to climb up through the ball nut until it hit the ceiling. There was a gouge in the concrete ceiling where the top of the screw had impacted. The drive mechanism to turn the ball screw consisted of a 70:1 worm gear reducer which was belt driven by a 1 HP motor. The gear reducer was not reversible due to the high ratio of the worm gear configuration. The reducer output was directly coupled to the ball screw through a jaw type flexible coupling. Although the bottom half of the coupling was still attached to the gear reducer output, the top half was free to move axially on the ball screw. After taking notes and photographs and making some sketches, Williams felt that he had the information that he needed from the inspection. He and Thompson left but planned to meet again in about a week.[1]

* All names have been disguised.

1 (The photographs that Williams took of the failed equipment are attached as Exhibits 5 through 10.)

2 (See Exhibits 1 through 4 which were provided by the manufacturer of the teletherapy unit and were given to Williams by Thompson.)

In Thompson's office the next week, Thompson gave Williams a copy of a report done by the Food and Drug Administration and a news paper account of the accident. (Exhibits 11 and 12) The FDA became involved in the investigation of the accident because of the possibility of radiation leakage. In addition to the FDA report Thompson gave Williams the following other interesting information.

Thompson, on behalf of his client, Valley Medical Center, had filed suit against the manufacturers of the radiation teletherapy unit, Radiation Technology Limited, or RTL. Their contention was that the accident was entirely due to a defective unit and that the Clinic should be held blameless.

RTL's attorney, Mr. Jackson, however was alleging that there was no fault in the unit but that the Clinic personnel had been careless in the operation of the teletherapy unit. The deposition of a Mr. Arnold, an engineer with RTL, had stated that the most likely chain of events leading to the accident was that the Clinic operator of the unit had at some time lowered the sourcehead down onto a table or cart and continued to hold the motor control button in the DOWN position. This had the effect of driving the screw up through the ball nut and separating the two halves of the coupling. The coupling halves might not have actually separated but could have been just barely in contact and then become separated at the time of the accident.

Joe Williams collected the reports, documents, drawings etc that he had been given and returned to his office at Reliable to prepare his written report to Mr. Thompson. During his ensuing study of the accident, Williams attempted to determine exactly what had caused the accident. He reviewed the basic design of the positioning mechanism of the sourcehead, particularly from the "fail safe" standpoint and also the operating characteristics of ball screws and coupling devices. He also spent considerable effort in trying to reconstruct in his own mind the chain of events leading to the failure as alleged by RTL's attorney.

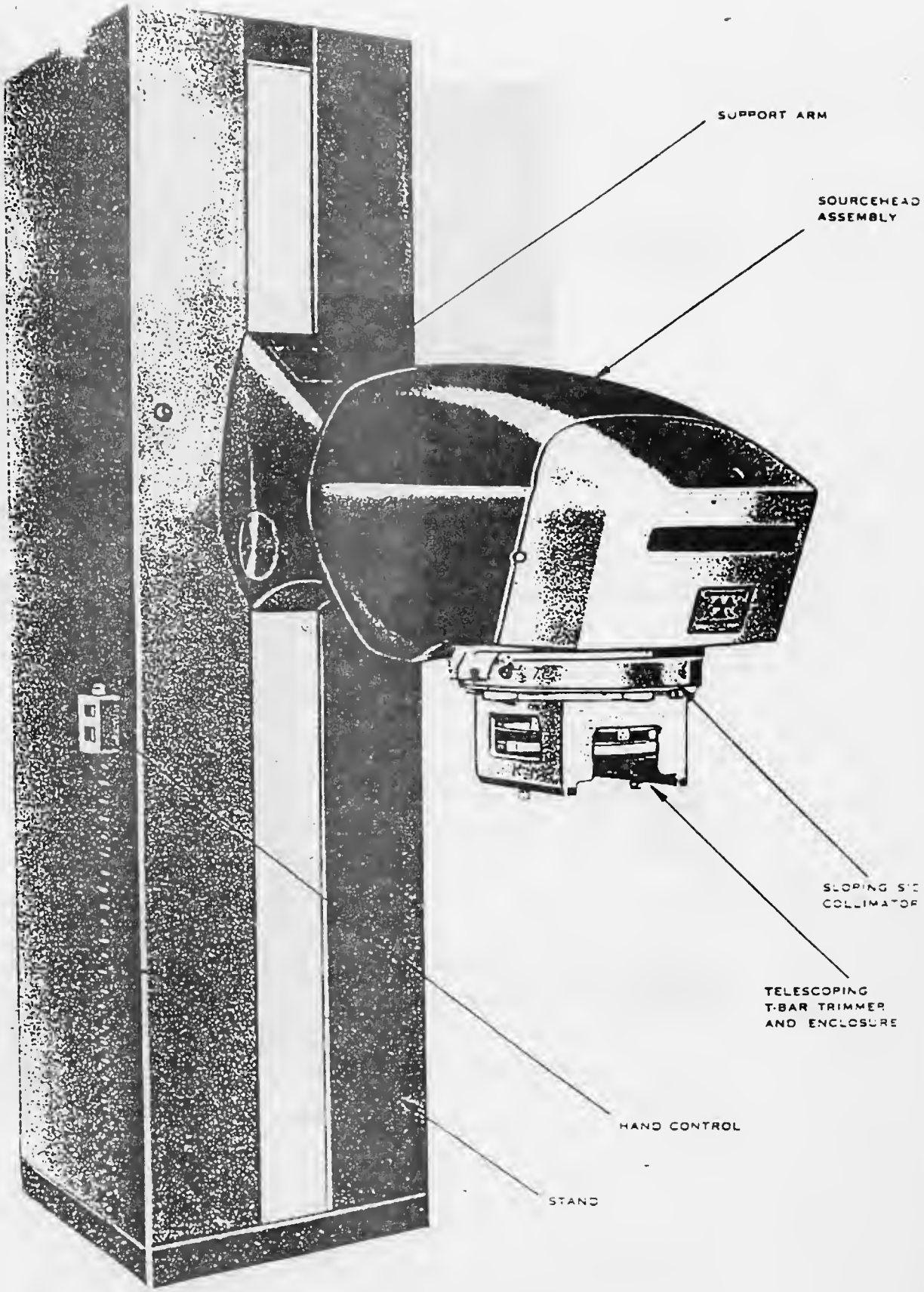

Exhibit 1 Overall View of Teletherapy Unit

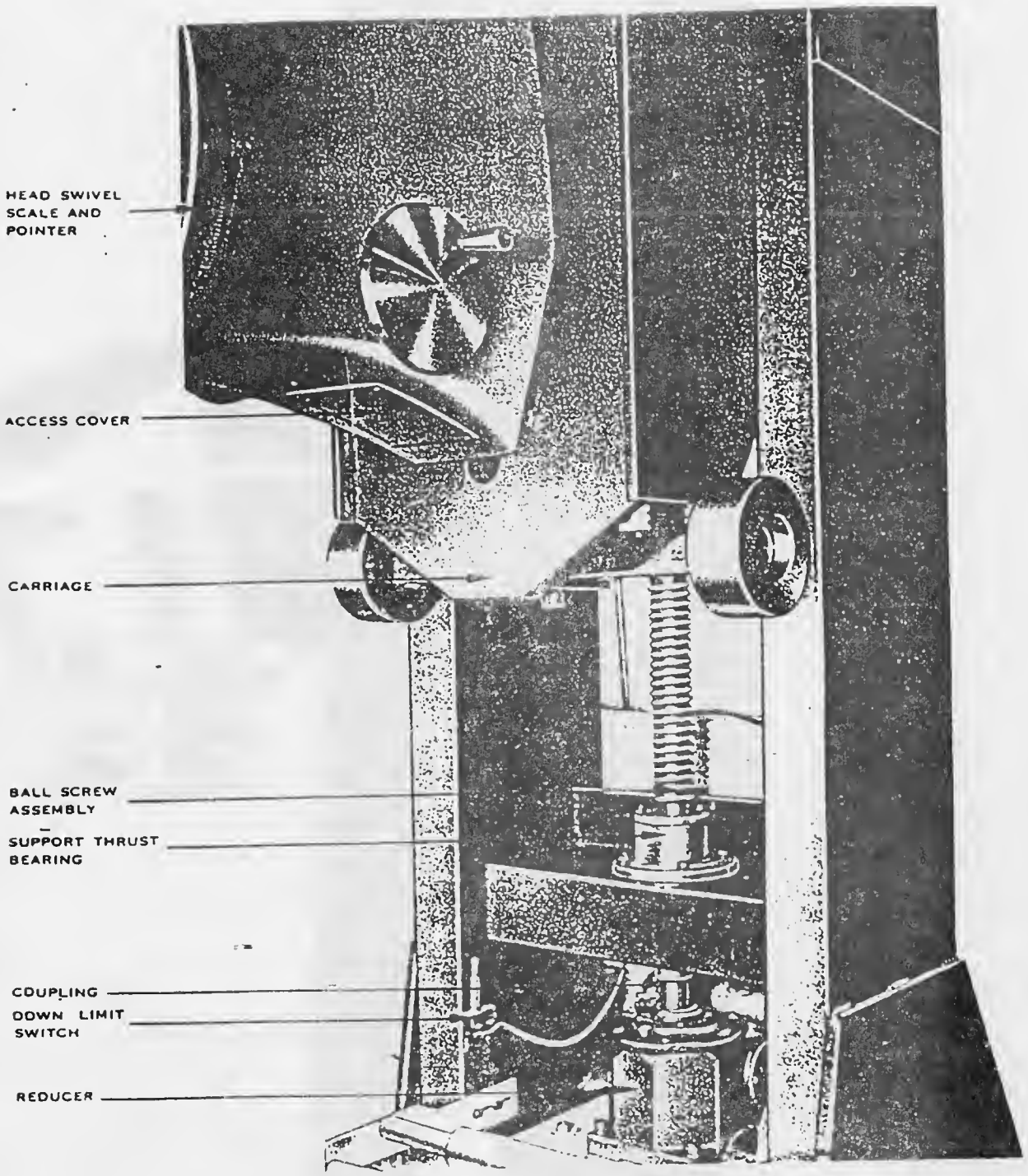

Exhibit 2 Elevation Drive - Front Cover Removed

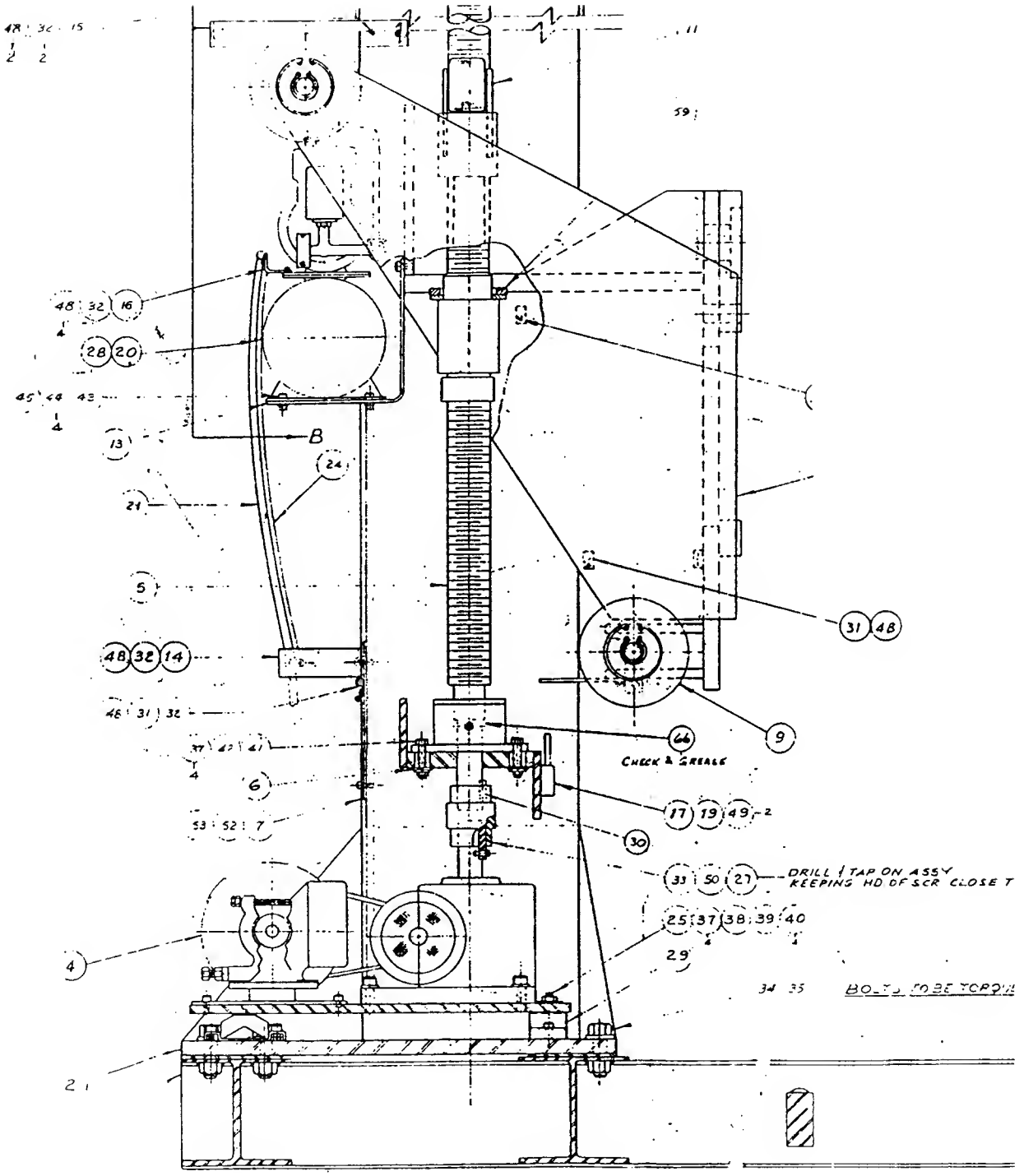

Exhibit 3 Assembly Drawing

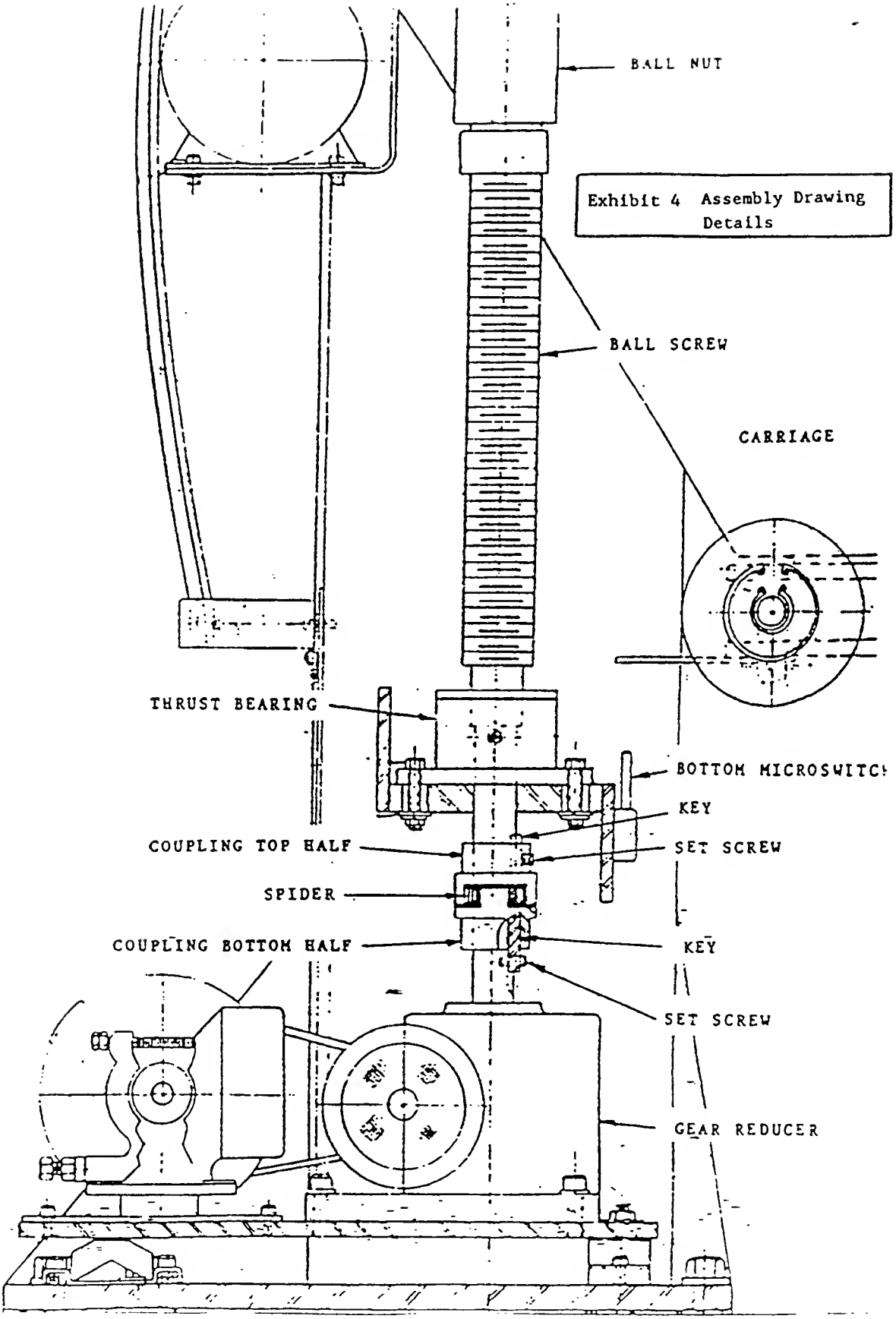

Exhibit 4 Assembly Drawing Details

Exhibit 5 Fallen Sourcehead

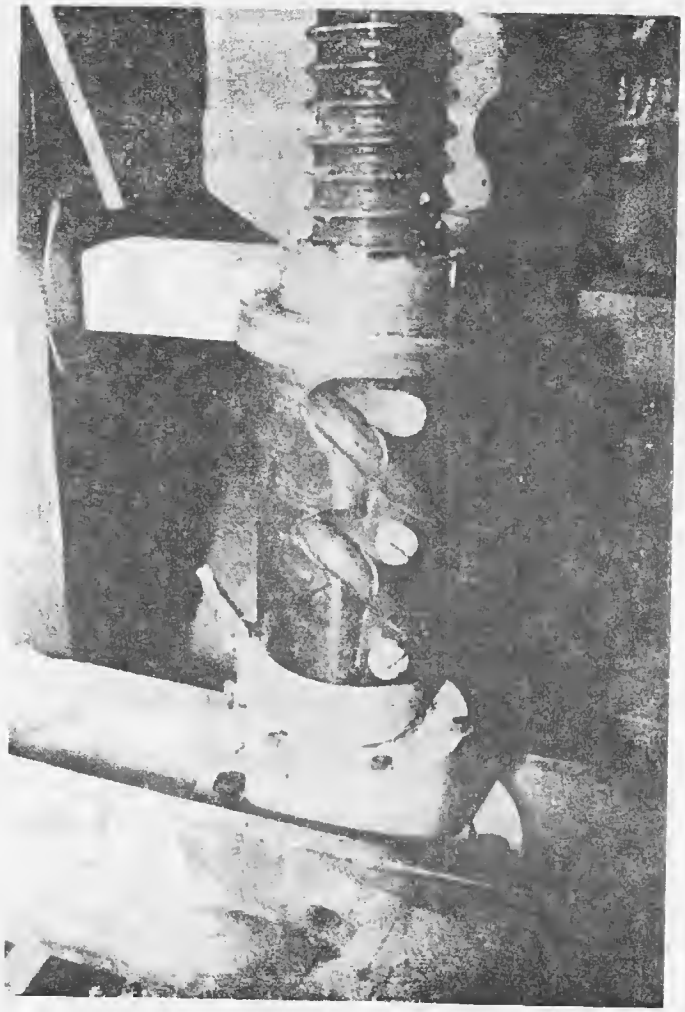

Exhibit 6 Ball Screw and Nut

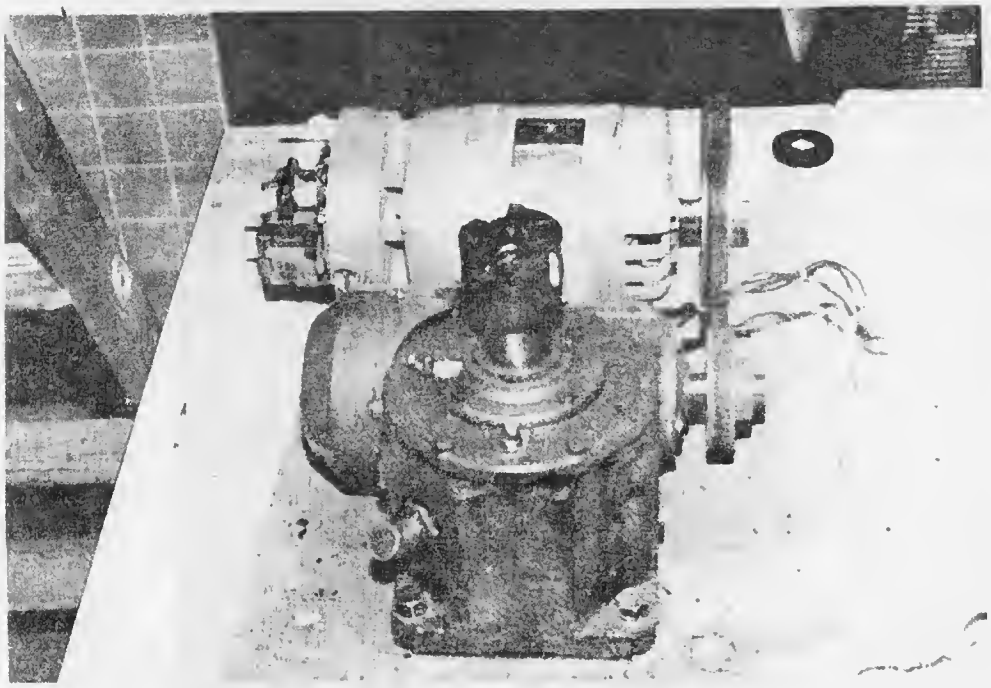

Exhibit 7 Reducer with Coupling

Exhibit 8 Lower Half of Coupling with Spider

Exhibit 9 Motor & Reducer Drive

Exhibit 10 Lower Half of Coupling

Outpatient crushed at hospital

A woman was killed this morning at County Hospital when the arm of a cobalt treatment machine fell on her head.

died about 7:45 a.m. from a crushed skull, said County coroner. Death was almost instantaneous, he said.

Mrs. an outpatient, was being prepared for a cobalt cancer treatment in the hospital's X-ray department. She was lying on a treatment table. A radiology technician was standing about a foot away and using a hand-held control to lower the arm of the machine.

The arm, which weighs 2,800 pounds and is about 4 feet long, descended automatically to about 18 inches above the woman's neck and head. Then, it "suddenly and abruptly gave way," said hospital public information officer.

Medical and hospital staff rushed to the scene as well as rescue workers from the Fire Department who took with them extrication equipment.

As emergency procedures were set to begin, the woman was declared dead.

"It's a tragedy. Never have we had anything like this happen at the hospital," said.

He said the machine's movement and the safe use of the radioactive cobalt were checked earlier this morning as they are every morning it's to be used. "and both the movement checks and cobalt checks were as specified."

After the accident, the room was checked for any cobalt leakage. There was none.

Three representatives of the Nuclear Regulatory Agency were en route to at noon today by chartered jet to investigate the incident.

public affairs officer for the NRC's office, said the NRC is the federal agency which regulates the use of radioactive materials. "And that's why we're inolved."

said that, as far as his people know, there was no radiation leakage.

agreed, saying that sensors and alarms in the room did not activate after the incident, and manual checks later did not show any sign of leakage.

said it's standard procedure for the NRC to investigate any accident involving radioactive material. He said a representative with the Food and Drug Administration's office also was traveling to to investigate since the FDA has jurisdiction over

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*HOSPITAL

(Continued From Page 1)

use of medical equipment.

said the cobalt contained in the hospital's machine, about 4,000 curies, would cause harm to anyone not shielded from it. The cobalt is encased in a capsule inside the machine, and then is protected by several layers of steel, accounting for the heavy weight of the machine's arm.

said cobalt is a radioactive spurce which alters the division cycle of cancer cells with the intent to stop their growth.

On a typical day, he said, the machine is used for up to 14 procedures.

The machine was purchased in December "Relatively speaking, it's a young machine," said.

"It always has worked satisfactorily and there never has been any notice that such equipment has had this kind of problem," said.

Detective of the County Sheriff's Department is conducting an investigation with Coroner to determine the cause of the accident.

Exhibit 11 Account in Local Newspaper

RESULTS OF FDA INVESTIGATION

SUMMARY OF FINDINGS

This was an investigation of a failure of a teletherapy unit conducted as a follow-up to a patient death resulting from the fall of the sourcehead during preparation for a Cobalt 60 treatment.

Results showed that two setscrews in the upper half of a coupling in the drive system of the unit did not prevent the coupling from moving up the shaft end and disengaging from its lower half. This allowed the shaft (ball screw) to spin freely. The head and carriage ride up and down on the ball screw shaft as it turns, and thus was allowed to fall essentially unimpeded. There was no system for preventing uncontrolled descent in the event of the failure of this coupling. Additional damage to the other parts of the device occurred during the fall of the head and after its impact.

Evidence shows that at least one of the two setscrews was never tightened, and that both setscrews were loose at the time of the incident. Evidence does not clearly show whether the second setscrew was never tightened or whether it was tightened and worked loose.

Examination of the lower half of the coupling, which had not failed but was slightly displaced downward, showed that the two setscrews corresponding to those in the upper coupling were less than finger tight (8 inch-ounces and 10 inch-pounds). It is not known if the setscrews were loose before the incident or as a result of the incident. The third setscrew was designed to be threaded through the key into the shaft and was found to be cut off short, serving no purpose.

FAILURE MODE

The accident occurred as the operator was adjusting the patient position and lowering the sourcehead to the treatment position. The patient was on her right side, the collimator of the sourcehead approximately over her neck. The operator was lowering the sourcehead and was approximately 5-10 cm above her treatment distance, which was to be 80 cm from the source to the patient.

The cause of the accident was the failure of the coupling halves to stay engaged. The upper half of the coupling was not secured in place by the setscrews and was allowed to work up the shaft. When the teeth disengaged from the teeth of the lower coupling, the ball screw shaft was allowed to spin freely under the weight of the sourcehead and carriage. This allowed the sourcehead and carriage to fall.

The large weight of the sourcehead as it fell provided the energy to cause the ball shaft to spin to very high speeds. When the sourcehead hit the floor the shaft continued to spin, climbing on its threads through the ball nut. The vertical motion of the shaft was stopped when it impacted against the ceiling, which was made of acoustic tile and approximately four feet of concrete for radiation shielding.

INSTRUCTOR's NOTES

Ball screws are low friction devices which replace the sliding friction of conventional power screws with the rolling friction of bearing balls which are contained in a ball nut. The bearing balls circulate in hardened steel races formed by concave helical grooves in the screw and nut. As the screw and nut rotate relative to each other the bearing balls are diverted from one end and carried by the ball guide return tubes to the opposite end of the ball nut.

The very low friction of ball screws produces a significant characteristic. Unlike a sliding friction screw (automotive scissors type jacks, house jacks, etc) a ball screw can be back driven; that is, it is reversible. For this reason the ball screw itself, or shaft, must be restrained in order to prevent a load on the ball nut from driving (rotating) the screw.

SAGINAW STEERING GEAR HiTec 90+ BALL SCREW SYSTEMS

Ball-bearing screw assembly with a portion of the nut cut away to show construction. (Courtesy Saginaw Steering Gear Division, General Motors Corporation.)

Definition of a Ball Screw

Saginaw Steering Gear HiTec 90+ Ball Screw Systems are force and motion transfer devices belonging to the family of power transmission screws. They replace the sliding friction of the conventional power screw with the rolling friction of bearing balls. The bearing balls circulate in hardened steel races formed by concave helical grooves in the screw and nut. All reactive loads between screw and nut are carried by the bearing balls which provide the only physical contact between these members. As the screw and nut rotate relative to each other, the bearing balls are diverted from one end and carried by ball guide return tubes to the opposite end of the ball circuit. This recirculation permits unrestricted travel of the nut in relation to the screw.

Advantages

- High efficiency — approximately 90%
- Smaller power source and transmission components
- Negligible heat expansion due to friction — no stick-slip
- Predictable life expectancy
- Higher reliability under varied operating conditions
- Permits preload for optimum spring rate and minimal ("zero") backlash
- Stepless control over entire stroke
- Position repeatability
- Uniform feed under varying load conditions
- Multiple screws can be synchronized

Typical Uses

MACHINE TOOLS — NC/CAM positioning and feed; Drives for conventional tables and slides; Robotics

AIRCRAFT — Flap and slat drives; Stabilizer trim; Landing gear actuators; Canopy actuation; Air inlet control; Thrust reversers; Fuel control actuators

WEAPON SYSTEMS — Elevation actuation on cannon, missile and rocket launchers; Leveling jacks

MATERIAL HANDLING — Balance hoist; Conveyor drop section; Die table; Crane boom actuator

MISCELLANEOUS — Jacks; Antenna leg actuators; Hospital bed articulation; Valve operators; Instrument drives; Dish antenna drives

Assignment for Students

Place yourself in the position of Williams. Prepare a letter to Mr. Y. Thompson, Esq., 34 River Plaza, Suite 4, St. Louis, MO. Indicate your opinion of the cause of the sourcehead collapse. Indicate whether you feel that the cause was due to a design defect or to an operator error. Suggest alternative design configurations that could have prevented the accident.